Seismograms from the Interactive Deaggregation Web page

Introduction

The 1997 ATC 35-3 workshop on improved characterization of strong ground shaking for seismic design recommended that suites of time series of ground motion should be available to engineers, in the form of an internet-accessible jukebox of strong-motion records and their characteristics (Applied Technology Council, 1999). Several such internet sites now exist. One of the most comprehensive is COSMOS, with address http://www.cosmos-eq.org.

ATC-35 further suggested that time-domain earthquake records could be tied to the USGS seismic hazard deaggregation web-site so that accelerograms for specific tectonic regimes and for modal-event magnitude and distance pairs could be published on demand. The deaggregation web site does not currently access COSMOS seismograms, but interested engineers are encouraged to do so. Instead, in this demonstration project, we generate synthetic seismograms using a well-tested method. Random-component horizontal accelerograms are generated from the program SMSIM_TD, version 2.10, by David M. Boore. SMSIM_TD uses the stochastic method and assumes a point source. Here, SMSIM_TD is modified to run in the context of a PSHA deaggregation. Boore (2000) describes his program and input parameters, and gives several references to the methodology. We note that many modal-event magnitude, distance, or (M,R), pairs, especially for sites in the central and eastern U.S. (CEUS), but also for many sites in Alaska, the Pacific Northwest, and even parts of California, correspond to potential earthquakes for which no strong-motion records from similar historical earthquakes exist at COSMOS or other strong-motion data Web sites. Synthetic seismograms may be useful for filling gaps in empirical data.

At this web site you can now obtain six seismograms for the most likely (M,R) or for the mean (M,R) that is determined during the interactive seismic hazard deaggregation from your specific input parameters. To exercise this option, answer "Yes" to the question, "Do you want seismograms for the modal or mean event?" The result will be two files, one containing ASCII seismograms and parameter information, and the other containing pictures of those six records. The records are generated assuming an event (M,R) equal to the mean or modal pair for your site/spectral period/return time.

Synthetic Seismogram Scaling

Each of the records is scaled to the ground motion [spectral acceleration ([SA]()) or peak horizontal ground acceleration ([PGA]())] whose period and probability of exceedance ([PE]()) were those that you requested in the interactive deaggregation menu. For example, if you requested 2.0-second SA for the 10% PE in 50 years, and if the probabilistic 2-second SA computed for your site's coordinates is 0.1 g, then each of the six seismograms is scaled so that its 2.0-second SA, with 5% damping, is 0.1 g. Denote the scale factor for the *i*th seismogram SF_i.

Denote the average scale factor, $ASF = \frac{1}{n}\sum SF_i$, where *n* is the number of seismograms generated. *ASF* is

reported in the ASCII header information.

***ASF* will tend to increase as PE decreases. If *ASF*=1, then the PSHA SA value equals the SA of the generated seismograms on average. ASF=1 should correspond to $\varepsilon_0 \approx 0$ for the PSHA mean or modal source. For any ε_0 associated with the PSHA mean or modal source, you should expect *ASF* to approximately equal exp[$\varepsilon_0 \sigma$], where σ is the aleatory uncertainty in ground motion, sometimes denoted $\sigma_{\ln y}$ in strong-motion regression equations. Empirical estimates of $\sigma_{\ln y}$ are generally in the range 0.5 to 0.6.**

Source, Path, and Site Effects

All of the parameters that are required by SMSIM_TD are reported in the header information which precedes the ASCII seismogram data. For sites in the CEUS, and for some sites in the WUS east of the Intermountain Seismic Belt, the deaggregation version of SMSIM_TD invokes the "Frankel" attenuation model and other parameters that were used to generate data for the 1996 national seismic hazard maps (Frankel *et al*, 1996).

For most sites in the western U.S., one of three source/propagation/site models is currently used. For most WUS (M,R) pairs having M<7.75 and R<100 km, the input parameters correspond to Boore's coastal California input file (Boore, 2000). For subduction events in Cascadia and Alaska, and for other Pacific Northwest and Alaska seismicity (latitude > 41° N, longitude > 120° W), we use parameters based on those reported in Atkinson and Boore (1997). For many other (M,R) pairs, the input parameters are those of the WUS point source, described by Atkinson and Silva (1997) and Atkinson and Boore (1998). The rule for using a CEUS attenuation model for certain sites in the WUS is that CEUS-catalog sources contribute more than 50% to the ground motion exceedances at that site, and the dominating (modal) event is not from a WUS fault. WUS faults occur west of the Rocky Mountain Front Range.

Thus, some tectonic-regime specificity exists for the generated seismograms. Earthquakes associated with some seismo-tectonic regimes that we would like to model are not currently modeled. Earthquakes in volcanic source regions such as Coso and Long Valley Caldera and earthquakes in extensional regimes such as the Basin and Range are two examples. As of 2001, we do not have seismic hazard deaggregations for sites in Hawaii.

Modeled site conditions should approximately equal firm rock. In the CEUS, rock with average Vs=760 m/s in the upper 30 m is modeled, whereas in the WUS, the exact NEHRP site class is not specified. This web site does not model variable site conditions such as local soil amplification and attenuation.

Selecting Records for Publishing

We believe that the response spectra, $PSA(f)=\omega PSRV(f)$, of the seismograms that we publish should have a limited variability at frequencies of greatest engineering interest. A set of 60 seismograms is generated by SMSIM_TD, and each is scaled so that its pseudo spectral acceleration (*SA* or *PSA*) at the specified wave period equals the probabilistic ground motion. We select a subset whose response spectra most closely match an approximate uniform hazard response spectrum, *U(f)*, over most of its domain.

***U(f)* is defined in Leyendecker *et al*. (2000) Here, we assume that *U(f)* has ordinates at 1.0 Hz and at 5.0 Hz equal to those of the interactive PSHA deaggregation. Call these ordinates *SA*1 and *SA*5, respectively. *SA*1 and *SA*5 correspond to the PE that you choose in your interactive seismic hazard deaggregation. Your choice may or may not equal the 2% in 50 year PE of the IBC-2000, discussed by Leyendecker *et al*. (2000). Because the**

accelerograms represent random motion, we cannot expect any given record's *PSA(f)* to closely approximate *U(f)*. We compute *PSA(f)* for those 60 seismograms and select the half dozen which most closely approximate *U(f)* in the 1 Hz to 5+ Hz (0.2- to 1.0 sec period) band, using an L_1 norm (least absolute percent deviation). That is, for j=1,2,3,...,60, we compute $S_j=\sum_i \left|\log[\, PSA_j(t_i) / U(t_i)]\right|$ where $t_i=1/f_i$ is sampled at 0.1-sec intervals in the 0.2 to 1 sec period band, and at the short-period corner of *U(t)*, t_s , where $t_s = 0.2*SA1/SA5$. We sort S_j and publish the six records having the smallest *S*. Outside that period or frequency band, we do not attempt to fit *U(t)*. Our experience is that *PSA(t)* will differ from *U(t)* by about 10% to 15% on average for the best-fitting 6 accelerograms for periods from 0.2 to 1 sec. If the PSHA is for 2-second (0.5 Hz) SA, the best-six's SA ordinates generally exhibit a similar variation in the 1 to 2 second band. In the output files, simulated accelerograms are labeled by their L_1 rank: A1 is the best fit, and A6 the 6th-best fit. Note that other than the scaling defined above, there is no "tweaking" of the data from SMSIM_TD, merely selection based on a criterion that we hope is helpful to structural engineers.

The above seismogram selection process based on spectral-ordinate matching only occurs if the user is calculating hazard for a non-zero spectral period. On the interactive deaggregation menu page, the user should select 1 Hz or 5 Hz and the 2% in 50 year PE if his/her application requires synthetic seismograms whose response spectra attempt to match the UBC 2000 code's approximate uniform hazard spectrum. If you select 1 Hz, your seismograms will have an exact spectral match at 1 Hz, whereas if you select 5 Hz, your seismograms will match at 5 Hz. If you select 3.3 Hz, the 3.3-Hz ordinate is scaled to equal the PSHA motion. Thus, in general, the 3.3-Hz ordinate will not match *U*(3.3 Hz).

If PGA (which is often plotted as 0.0-second period SA) is selected on the menu page, only six accelerograms are computed. Each of these is scaled to have the PGA of the PSHA. If PGA is selected on the menu page, no effort is currently made at this web-site to fit *U(t)* for $t > 0$. If you just want to look at some synthetic seismograms, but don't care about *U(t)*, select PGA for a faster run. If you consider PGA to be equivalent to a 0.01-sec SA, the stochastic seismograms' PGA appears to be consistent with *U(.01 s)*, i.e., we find no anomalous behavior of SA at very short periods. Boore (2000) shows close agreement between PSA from time domain simulations and that determined using random vibration theory at periods as short as 0.01 seconds.

An Example.

It may be instructive to look at the performance of the "L1 fitting criterion" for a specific site. Figure 1 exhibits the approximate uniform hazard spectrum, *U(t)*, as a solid curve, and the 2% in 50 year PSHA SA values as dashed curve for a site in Indianapolis, Indiana. Stochastic seismograms for the mean (R,M) were computed at this interactive deaggregation web site for the 0.2 second and 0.3 second periods. For the 0.2 second period, the mean (R,M)=(219 km, 6.65) and for the 0.3-second period, the mean (R,M)=(256 km, 6.95) using the 1996 USGS seismic hazard model. Figure 1 illustrates the results of using the above L1 fitting criterion to the 2% in 50 year PSHA data, with circle symbols showing the computed SA values for the best fitting seismogram, and square symbols for the 5th best fitting seismogram. The analysis for the left graph of Figure 1, labeled A, scales the records to match the 0.2-second PSHA SA (179 cm/s/s), and the analysis for the right graph, labeled B, scales the records to match the 0.3-second PSHA SA value (161 cm/s/s). You can see that the circles and squares of graph B fit *U(t)* about as well as those of graph A, at least for the periods used to determine goodness of fit.

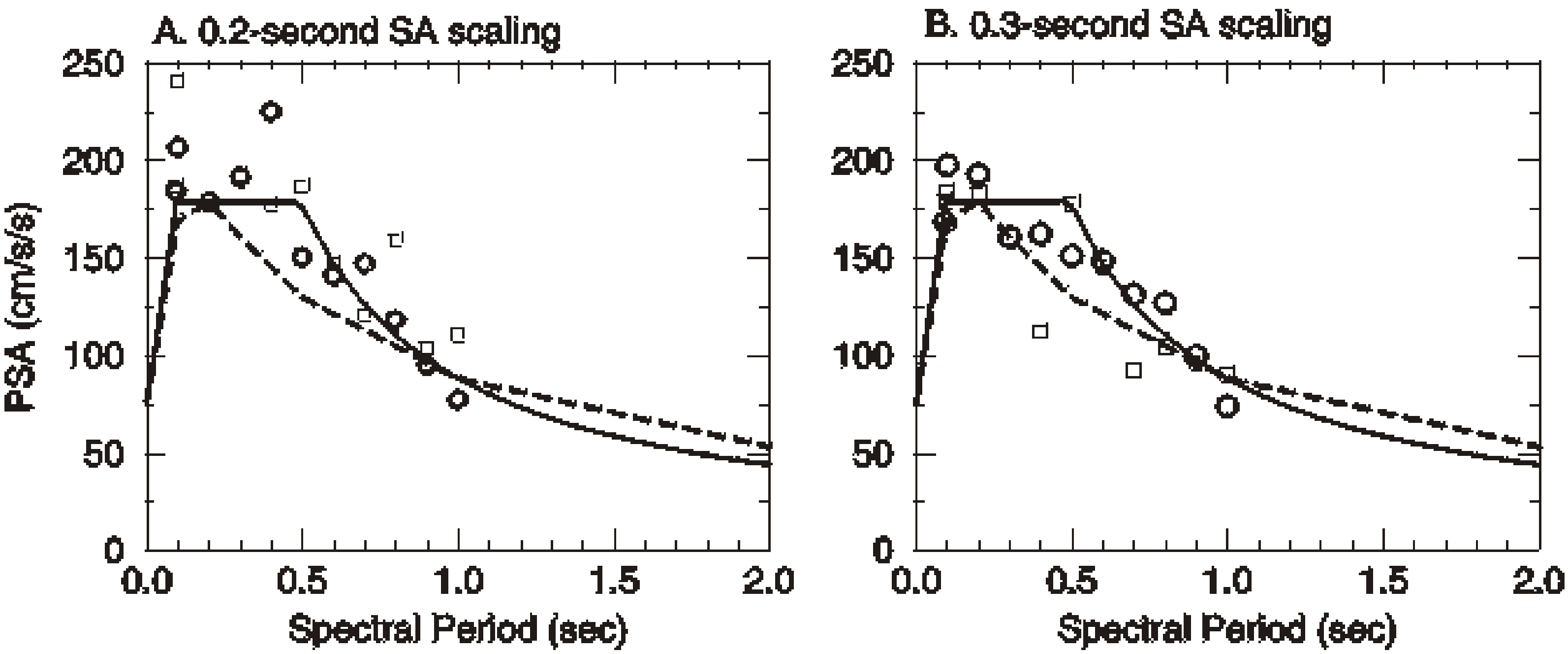

Figure 1

Caveats

Many issues in model uncertainty suggest caution when using SMSIM seismograms for specific applications. We are not in a position to offer blanket endorsement of either stochastic method seismograms or real strong-motion data for any specific application. Sometimes distinctly different (M,R) pairs should be used to fit different "periods" of *U(t)* (McGuire, 1995), even though the selection process defined above publishes seismograms from a single (M,R) that attempt to fit *U(t)* over the band 0.2 to 1.0 seconds. At some sites, strong-motion signal duration, which generally increases with M and *R* (for example, Atkinson and Boore, 1998), may be an important design consideration that may not be adequately captured by "short-period" (M,R) pairs. The short article "mean or mode?" at this web site contains other caveats.

The accelerograms of SMSIM_TD correspond to a point source. Users who are interested in finite-fault effects are cautioned that the output of SMSIM_TD will not capture many of these effects, such as source directivity and radiation pattern lobes and nodes. Important propagation effects such as the generation of basin surface waves are not included in SMSIM_TD. Soil amplification and attenuation are not modeled.

We are experimenting with ways to bring greater realism to the interactive deaggregation Web-site seismogram option. Although we are interested in improving our capabilities for online simulation of larger earthquake records, for example, plate subduction events in Alaska and Cascadia, M 7.8+ strike-slip earthquakes on the San Andreas fault, and large earthquakes in the New Madrid Seismic Zone, the computing burden should be recognized.

Several Fortran programs that use the stochastic method to generate motion on finite faults are available to interested scientists and engineers and some are being considered for automatic time-series generation at this web-site. A web-site article by Y.K. Wen and C.L. Wu that uses the Beresnev-Atkinson finite-fault stochastic seismogram method for generating realistic seismograms for select cities in the CEUS has URL http://mae.ce.uiuc.edu/temp/simulation.html.

Atkinson and Silva (1997) find that their proprietary code finite-fault simulations tend to match empirical near-source spectra better than Brune point-source models for periods greater than 1 second when compared over a broad range of M. The intermediate to long period "spectral sag" of empirical data for M > 6.5 earthquakes compared to the Brune point-source prediction is often noted in source-theory research. If the spectral sag feature is desired for WUS site seismograms, one can run Boore's SMSIM_TD, but should use a two-corner source parameter file rather than the Boore coastal California parameter file for generating stochastic seismograms. Atkinson and Silva (2000) give background and details for f_A , f_B, and ε for a particular 2-corner model that they find is just about as good as finite fault models for simulating average ground motion from M > 6.5 earthquakes. Similarly, for modeling spectral sag at CEUS sites, a parameter file with a two-corner source should be prepared and used rather than Frankel's attenuation model, which uses the 1-corner Brune source spectrum. We may include the option to compute seismograms using a 2-corner source spectrum at this web-site. Perhaps it should be emphasized that azimuthal variation from source directivity is not achieved by two-corner source models any more than by the single-corner (Brune source) model.

Evolution of Product

This demonstration project for on-the-spot generation of accelerograms should evolve rapidly with constructive inputs from seismologists and engineers. Some modifications were made in mid-November, 2001, to this document and to the software in response to early suggestions from users. In particular, two changes are noted.

(1) The ordinate at t_s , the short period corner of *U(t)*, is now included in the spectral ordinate period band for which an approximate match is sought.

(2) Visitors can choose the mean (M,R) rather than the modal (M,R) for generating seismograms corresponding to a representative magnitude and distance.

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